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The invention relates to a method for monitoring the stability of the carrier frequency of several transmitters in a single-frequency network.

Terrestrial digital radio and TV (DAB and DVB-T) are transmitted using digital multi-carrier methods (e.g. OFDM = orthogonal frequency division multiplexing) via a network of transmitters, which transmit within the transmission range in a phase-synchronous and frequency-synchronous manner via a single-frequency network.

For an efficient exploitation of the available frequency resources, all the transmitters of a single-frequency network simultaneously transmit an identical transmission signal. In addition to phase synchronicity, the identity of the carrier frequency to be transmitted in the individual transmitters must therefore also be guaranteed within a single-frequency network.

DE 199 37 457 A1 discloses a method for monitoring the phase synchronicity of individual transmitters of a single-frequency network. The occurrence of a phase synchronicity of two transmitters is registered via a measurement of propagation-time difference by determining the channel impulse responses of both of the transmitters. If a large-scale deviation between the measured propagation-time difference of the two transmitters and a reference propagation-time difference for synchronous operation of the two transmitters is registered, then the transmitters are transmitting in an asynchronous manner. This deviation in the propagation-time difference is determined by a receiving station

within the transmission range of the single-frequency network by evaluating the channel impulse responses and communicated to the two phase-asynchronous transmitters to allow subsequent synchronisation. A method for monitoring identical carrier frequencies in two transmitters within a single-frequency network is not disclosed in DE 199 37 457.

The synchronisation of transmitters in a single-frequency network with regard to an identical carrier frequency is described in DE 43 41 211 C1. In this context, alongside the transmission data, a central system also transmits a frequency reference symbol to the individual transmitters of the single-frequency network. This frequency reference symbol is evaluated by every transmitter in the single-frequency network and is used to synchronise the carrier frequency with the reference frequency .

The disadvantage with this method is the fact that the synchronicity of the carrier frequency is evaluated by each transmitter individually. Accordingly, this transmitter-specific evaluation of the frequency synchronicity of the carrier frequency may be associated with a certain transmitter-specific measurement and evaluation error, which can lead to a non-uniform monitoring of the carrier frequencies of all the transmitters participating in the single-frequency network. Added to this is the fact that the monitoring of the carrier frequency in each individual transmitter necessitates a synchronisation of the individual transmitters by means of a time reference, which is received by the individual transmitter, for example, via GPS. Frequency synchronisation in the circuit arrangement according to DE 43 41 211 C1 finally takes place before

modulation. A retrospective frequency displacement of the carrier frequency by subsequent functional units of the transmitter is therefore not excluded. All of these disadvantages can lead to an undesirable reception of different carrier frequencies of the individual transmitters in a receiver positioned anywhere within the transmission range of the single-frequency network.

The invention is therefore based on the object of providing a method and a device for monitoring the carrier frequency stability of transmitters in a single-frequency network, wherein the synchronicity of the carrier frequencies of the individual transmitters is monitored in a uniform manner by a single measurement arrangement, which can be positioned anywhere within the transmission range of the single-frequency network without a synchronisation of the measurement arrangement by means of a time reference.

The object of the invention is achieved by a method for monitoring the carrier-frequency stability of transmitters in a single-frequency network with the features of claim 1, and by a device with the features of claim 12 or 13. Advantageous developments of the invention are specified in the dependent claims.

The carrier-frequency stability of the transmitter associated with a single-frequency network is monitored via a single receiver device, which is positioned anywhere within the transmission range of the single-frequency network. The receiver device determines the characteristic of the summated impulse response of all transmitters at two different times from the transmission function of the transmission channel, preferably using

the inverse complex Fourier transform. The impulse responses associated with each transmitter are masked out of the two summated impulse responses after their phase position has been compared with the phase position of the two impulse responses of a reference transmitter of the single-frequency network. The phase characteristics of the two impulse responses associated with each transmitter are then determined. The phase-displacement difference of the impulse responses of each transmitter relative to the phase position of the impulse response of the reference transmitter between two observation times is once again derived from these phase characteristics. The carrier-frequency displacement of every transmitter relative to the carrier frequency of a reference transmitter of the single-frequency network can be calculated from the characteristic of the phase-displacement difference, as shown in greater detail below.

To allow an unambiguous identification of a permanent carrier-frequency displacement in a transmitter of the single-frequency network, the summated impulse responses of all transmitters are implemented repeatedly from the transmission function of the transmission channel by applying the inverse complex Fourier transform at several different times. The carrier-frequency displacement of every transmitter relative to the carrier frequency of a reference transmitter of the single-frequency network is calculated repeatedly on this basis and supplied for subsequent averaging.

If the phase-displacement difference of a transmitter decreases between two times to a value smaller than $-\pi$, or if the phase-displacement difference of a transmitter

rises between two times to a value greater than $+\pi$, then the value of the phase-displacement difference of each transmitter between two times within this time segment is increased by the value $+2*\pi$ or respectively reduced by $2*\pi$. In this manner, the phase-displacement difference is limited to values between $-\pi$ and $+\pi$.

The impulse response of every transmitter of the single-frequency network is obtained by determining the coefficients of the transmission function of the transmission channel from the coefficients of the equaliser adapted to the transmission channel in the receiver device. This is followed by a calculation of the inverse Fourier transform. In the case of digital terrestrial TV (DVB-T), the impulse response for every transmitter can alternatively be derived from the inverse Fourier transform of the transmission function of the transmission channel by evaluating the OFDM-modulated transmission signals associated with the scattered pilot carriers.

Two embodiments of the invention are illustrated in the drawings and described in greater detail below. The drawings are as follows:

Figure 1 shows a functional presentation of a device according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network;

Figure 2 shows an exemplary graphic presentation of the time-discrete, summated impulse response;

Figure 3 shows an exemplary graphic presentation of a modification of the characteristic for the transmission function of the transmission channel;

Figure 4A shows a flow chart explaining the first embodiment of the method according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network;

Figure 4B shows a flow chart explaining the second embodiment of the method according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network;

Figure 5A shows an exemplary presentation of results for the first embodiment of the method according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network;

Figure 5B shows an exemplary presentation of results for the second embodiment of the method according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network;

Figure 6A shows an exemplary three-dimensional graphic presentation of the amplitude deviation and carrier-frequency deviation and

Figure 6B shows an exemplary two dimensional graphic presentation of the amplitude deviation and carrier-frequency deviation.

The method according to the invention for monitoring the carrier-frequency stability of transmitters in a single-frequency network is described below on the basis of two embodiments with reference to Figures 1 to 5.

The transmitters $S_0,\dots,S_i,\dots,S_n$, for instance, according to Figure 1, each of the transmitters S_1, S_2, S_3, S_4 and S_5 transmits an identical phase-synchronous and frequency-synchronous signal s(t), for example, within the context of digital radio and TV. A receiver device E, which is positioned within the transmission range of the single-frequency network, receives a received signal e(t) as a superimposition of all of the received signals $e_i(t)$ associated with the individual transmitters $S_0,\dots,S_i,\dots,S_n$. This superimposed received signal e(t) provides the following time characteristic according to equation (1):

$$e(t) = \sum_{i=0}^{n} e_i(t) = s(t) + \sum_{i=1}^{n} v_i * e^{j\Delta\omega_i t} * s(t-\tau_i) \qquad (1)$$

Within the framework of the following description, the transmitter S_0 is defined by way of example as the reference transmitter of the single-frequency network. The attenuation and phase distortions, and the propagation times experienced by the transmitted signals s(t) of the individual transmitters $S_0,\dots,S_i,\dots,S_n$ in the transmission channel to the receiver device E, are compared respectively with the attenuation and phase distortion, and the propagation time of the reference transmitter S_0. The signal $e_0(t)$ of the reference

transmitter S_0 received in the receiver device E in equation (1) therefore corresponds to its transmitted signal s(t).

The amplitude v_i of the received signal $e_i(t)$ of the other transmitters S_1 to S_n is derived according to equation (2) from the attenuation scaling as a quotient of the amplitude of the received signal $e_i(t)$ of the respective transmitter S_i and the amplitude of the received signal $e_0(t)$ of the reference transmitter S_0:

$$V_i = | e_i / e_0 | \tag{2}$$

The propagation-time difference τ_i of the transmitters S_1 to S_n can be calculated according to equation (3) from the difference between the propagation time t_i of the transmitter S_i and the propagation time t_0 of the reference transmitter S_0:

$$\tau_i = t_i - t_0 \tag{3}$$

The propagation time differences τ_i of the individual transmitters S_0 to S_n are based upon the following effects:

- different propagation times because of different distances between the respective transmitters S_i and the receiver device E and

- different phase distortions of the transmitted signals s(t) of the respective transmitters S_i over the different transmission distances to the receiver device E.

An additional phase displacement $\Delta\Theta_i$ between a transmitter S_i and the reference transmitter S_0 can occur in the case of phase scaling of the received signal e(t), if, according to equation (4), a difference occurs in the carrier frequency ω_i of the respective transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0:

$$\Delta\Theta_i = \Theta_i - \Theta_0 = \omega_i * t - \omega_0 * t = (\Delta\omega_i + \omega_0) * t - \omega_0 * t = \Delta\omega_i * t \qquad (4)$$

The carrier-frequency deviation $\Delta\omega_i$ of the respective transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 leads, according to equation (4), to a phase displacement $\Delta\Theta_i(t)$ of the received signal $e_i(t)$ associated with the respective transmitter S_i.

Taking into consideration the correlation in equation (4), equation (1) is transformed for the time characteristic of the received signal e(t) according to equation (5)

$$e(t) = s(t) + \sum_{i=1}^{n} v_i * e^{j\Delta\Theta_i(t)} * s(t-\tau_i) \qquad (5)$$

If it is assumed according to equation (6), that the time duration Δt_B for the observation of the received signal $e_i(t)$ is substantially less than the duration for all phase rotations $\Delta\Theta_i(t)$ of the received signal $e_i(t)$ on the basis of a carrier-frequency displacement $\Delta\omega_i$ of the respective transmitter S_i, it can be assumed, that the

phase displacement $\Delta\Theta_i$ of the received signal $e_i(t)$ is approximately constant within this time slot Δt_B.

$$\Delta t_B << 2*\pi / \max \{\Delta\omega_i\} \qquad (6)$$

Equation (5) for time characteristic of the received signal e(t) is transformed into equation (7) for the time range of the time slot Δt_B.

$$e(t) = s(t) + \sum_{i=1}^{n} v_i * e^{j\Delta\Theta_i} * s(t-\tau_i) \qquad (7)$$

Figure 2 shows the connection between the scaling of the received signal $e_i(t)$ of a transmitter S_i relative to the received signal $e_0(t)$ of a reference transmitter S_0 with regard to attenuation and propagation time.

With a known transmission function of the transmission channel of the single-frequency network comprising the transmitters S_0 to S_n, the received signal e(t) can be understood through the summated impulse response $h_{SFN}(t)$ of the transmission channel of the single-frequency network composed of the respective impulse responses $h_{SFNi}(t)$ of the transmitters $S_0, \ldots, S_i, \ldots, S_n$ according to equation (8)

$$h_{SFN}(t) = \sum_{i=0}^{n} h_{SFN_i}(t) = \delta(t) + \sum_{i=1}^{n} v_i * e^{j\Delta\Theta_i} * \delta(t-\tau_i) \qquad (8)$$

The frequency spectrum $E(\omega)$ of the received signal e(t) in equation (9) is derived from the Fourier transform of the received signal $h_{SFN}(t)$ according to equation (8)

multiplied by the transmission function $S(\omega)$ of the transmission channel of the single-frequency network:

$$E(\omega) = S(\omega) * (1+\sum_{i=1}^{n} v_i * e^{j\Delta\Theta_i} * e^{-j\omega\tau_i}) = S(\omega) * H_{SFN}(\omega) \qquad (9)$$

The bracketed term of the frequency spectrum $E(\omega)$ of the received signal $e(t)$ in equation (9) corresponds to the transmission function $H_{SFN}(\omega)$ of the transmission channel of the single-frequency network. This consists of a sum of indices, of which the phases change with the term $j\omega\tau_i$ and, for a given time t, provide a constant phase displacement $\Delta\Theta_i = \Delta\omega_i * t$.

The value of the transmission function $|H_{SFN}(f)|$ for a single-frequency network with a reference transmitter S_0 and a second transmitter S_i is presented via the frequency f in Figure 3. The value of the transmission function $|H_{SFN}(f)|$ provides a periodic curve characteristic with a period of $1/\tau_1$. The characteristic for the value of the transmission function $|H_{SFN}(f)|$ is displaced from a periodic curve characteristic at time $t=t_1$ (continuous line) to a similarly periodic curve characteristic of the same period at a later time $t=t_2>t_1$ (dotted line) because of the influence of the phase displacement $\Delta\Theta_1$ of the received signal $e_1(t)$ of the transmitter S_1 relative to the received signal $e_0(t)$ of the reference transmitter S_0 because of a carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_1 relative to the carrier frequency ω_0 of the transmitter S_0.

The rate of displacement of the characteristic for the absolute value of the transmission function $|H_{SFN}(f)|$ is

determined through the carrier-frequency displacement $\Delta\omega_1$ of the transmitter S_1 relative to the carrier frequency ω_0 of the reference transmitter S_0. The required time t_{Per} for the displacement of the characteristic for the value of the transmission function $|H_{SFN}(f)|$ through exactly one period of the absolute-value characteristic of the transmission function $|H_{SFN}(f)|$ is derived according to equation (10) using equation (4) assuming a phase displacement $\Delta\Theta_i$ of $2*\pi$ in the case of a full rotation of the phase displacement $\Delta\Theta_i$:

$$t_{Per}=2*\pi \ / \ \Delta\omega_1 = 1 \ / \ \Delta f_1 \tag{10}$$

If the transmission function $H_{SFN}(f)$ is observed in two different time slots Δt_{B1} and Δt_{B2}, then, according to equation (4), the phase displacement $\Delta\Theta_i$ resulting from a carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 changes in the transmission function $H_{SFN}(f)$ over the time t between the time slot Δt_{B1} and the time slot Δt_{B2}, as does its characteristic over the frequency f. The characteristic of the summated impulse response $h_{SFN}(t)$ according to equation (8) corresponding to the transmission function $H_{SFN}(f)$ also changes in a similar manner.

With the change of the characteristic of the summated impulse response $h_{SFN}(t)$ in the case of a rotating phase displacement $\Delta\Theta_i(t)$ of the transmitter S_i from the time slot Δt_{B1} to the time slot Δt_{B2}, the characteristic of the impulse response $h_{SFNi}(t)$ of the transmitter S_i, of which the carrier frequency ω_i has been displaced relative to

the carrier frequency ω_0 of the reference transmitter S_0, also changes. The phase angle displacement $\Delta\Theta_i(t)$ of the impulse response $h_{SFNi}(t)$ associated with the transmitter S_i from the time t_{B1} of the time slot Δt_{B1} to the time t_{B2} of the time slot Δt_{B2} is, according to equation (11), therefore proportional to the characteristic of the carrier-frequency displacement $\Delta\omega_i(t)$ of the transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_i.

$$\Delta\Theta_i(t_{B2}) - \Delta\Theta_i(t_{B1}) = \Delta\omega_i(t)*(t_{B2} - t_{B1}) \qquad (11)$$

For reasons of simplicity, it is assumed that the carrier-frequency displacement $\Delta\omega_i(t)$ between the two observation times t_{B1} and t_{B1} does not change. Subject to this reasonable assumption, equation (11) is transformed into equation (12).

$$\Delta\Theta_i(t_{B2}) - \Delta\Theta_i(t_{B1}) = \Delta\omega i*(t_{B2} - t_{B1}) \qquad (12)$$

The first embodiment for monitoring the carrier-frequency stability of transmitters in a single-frequency network is therefore derived from the procedural stages presented below, as shown in Figure 4A:

In procedural stage S10, the transmission function $H_{SFN}(f)$ of the transmission channel of the individual transmitters $S_0,\ldots,S_1,\ldots,S_n$ of the single-frequency network to the receiver device E is determined. For this purpose, the characteristic of the transmission function $H_{SFN}(f)$ can be determined from the coefficients of the equaliser integrated in the receiver device E, which, in the case of an equaliser adapted to the transmission channel,

correspond to the coefficients of the transmission function $H_{SFN}(f)$.

In procedural stage S20, the characteristics of the associated complex, summated impulse responses $h_{SFN1}(t)$ and $h_{SFN2}(t)$ at the two times t_{B1} of the time slot Δt_{B1} and t_{B2} of the time slot Δt_{B2} are calculated by means of discrete, inverse Fourier transform. In this context, time-discrete, complex, summated impulse responses $h_{SFN1}(t)$ and $h_{SFN2}(t)$ at individual sampling times t are involved.

The characteristics of the complex impulse responses $h_{SFN1}(t)$ and $h_{SFN2}(t)$, associated in each case with the transmitters S_i participating in the single-frequency network, at the times t_{B1} and t_{B2}, are filtered out of the two time-discrete characteristics of the complex, summated impulse responses $h_{SFN1}(t)$ and $h_{SFN2}(t)$ in procedural stage S30.

In the case of digital terrestrial TV, as an alternative to determining the transmission function $H_{SFN}(f)$ of the transmission channel from the coefficients of the equaliser integrated in the receiver device, as presented above, the transmission function $H_{SFN}(f)$ of the transmission channel can be determined from the DVB-T symbols of the scattered carrier pilots.

Each of these time-discrete characteristics of the impulse responses $h_{SFN1i}(t)$ and $h_{SFN2i}(t)$ of the respective transmitter S_i at the times t_{B1} and t_{B2} is a complex numerical sequence. From these complex characteristics of the impulse responses $h_{SFN1i}(t)$ and $h_{SFN2i}(t)$, the associated time-discrete phase characteristics $\arg(h_{SFN1i}(t))$ and $\arg(h_{SFN2i}(t))$ of the respective transmitter S_i at the

times t_{B1} and t_{B2} are determined in procedural stage S40. Alternatively, the impulse response may not be allocated to the transmitters at this time, and only total impulse responses $h_{SFN1}(t)$ and $h_{SFN2}(t)$ are initially calculated.

By subtraction of the time-discrete phase characteristics $\arg(h_{SFN1i}(t))$ and $\arg(h_{SFN2i}(t))$ of the impulse responses $h_{SFN1i}(t)$ and $h_{SFN2i}(t)$ of the respective transmitter S_i at the times t_{B1} and t_{B2}, a phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ for the phase displacement of the respective transmitter S_i relative to the reference transmitter S_0 between the times t_{B2} and t_{B1} is obtained; this phase-displacement difference is constant over time and corresponds to the difference of the phase displacement $\Delta\Theta_i(t_{B2})$ at the time t_{B2} and the phase displacement $\Delta\Theta_i(t_{B1})$ at the time t_{B1} of the transmitter S_i relative to the reference transmitter S_0. In procedural stage S50, this is calculated according to equation (13) derived from equation (8):

$$\begin{aligned}\Delta\Delta\Theta_i(t_{B2}-t_{B1}) &= \arg(h_{SFN2i}(t)) - \arg(h_{SFN1i}(t)) \\ &= \Delta\Theta_i(t_{B2}) - \Delta\Theta_i(t_{B1}) \qquad (13)\end{aligned}$$

The phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 between the times t_{B1} and t_{B2} can, under some circumstances, adopt values smaller than $-\pi$, which are disposed outside the acceptable value range. Accordingly, in time ranges, in which the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 between the times t_{B1} and t_{B2} adopts values smaller than $-\pi$, the phase-displacement

difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement according to equation (14) is increased in procedural stage S60 by the value $2*\pi$.

$$\Delta\Delta\Theta_i(t_{B2}-t_{B1}) = \Delta\Delta\Theta_i(t_{B2}-t_{B1}) - 2*\pi$$
$$\text{for values of } \Delta\Delta\Theta_i(t_{B2}-t_{B1}) <= -\pi \qquad (14)$$

If the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 between the times t_{B1} and t_{B2} adopts values greater than $+\pi$, which are disposed outside the acceptable value range, then the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement is reduced by the value $2*\pi$ in procedural stage S65 according to equation (15).

$$\Delta\Delta\Theta_i(t_{B2}-t_{B1}) = \Delta\Delta\Theta_i(t_{B2}-t_{B1}) - 2*\pi$$
$$\text{for values of } \Delta\Delta\Theta_i(t_{B2}-t_{B1}) > \pi \qquad (15)$$

The limitations of the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 between the times t_{B1} and t_{B2} according to equations (13) and (14) implemented in procedural stages S60 and S65 guarantee an unambiguous phase value within the range from $-\pi$ to $+\pi$.

In procedural stage S70, the characteristic of the carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 between the times t_{B1} and t_{B2}, derived according to equations (12) and (13) from the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase

displacement of the transmitter S_i relative to the reference transmitter S_0 between the times t_{B1} and t_{B2}, is calculated according to equation (16).

$$\Delta\omega_i = [\Delta\Theta_i(t_{B2}) - \Delta\Theta_i(t_{B1})] / (t_{B2}-t_{B1})$$
$$= \Delta\Delta\Theta_i(t_{B2}-t_{B1}) / (t_{B2}-t_{B1}) \qquad (16)$$

Since, over the time t, additional phase changes resulting, for example, from phase noise, can be superimposed over the phase displacement $\Delta\theta_i(t)$ of the received signal $e_i(t)$ of the transmitter S_i, as a result of a carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_i relative to the reference transmitter S_0, as illustrated in Figure 5A, phase disturbances of this kind should be removed from the phase-displacement difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 between the two observation times t_{B1} and t_{B2}. This adjustment is provided in the second embodiment of the method according to the invention for monitoring the carrier frequency stability of transmitters in a single-frequency network as illustrated in Figure 4B.

The first embodiment shown in Figure 4A differs from the second embodiment shown in Figure 4B, in that the phase-displacement difference $\Delta\Delta\Theta_i(\Delta t_B)$ of the phase displacement of the transmitter S_i relative to the reference transmitter S_0 within a time interval Δt_B is determined, in procedural stage S50, not only between the observation times t_{B1} and t_{B2}, but at several other observation times t_{Bj} and $t_{B(j+1)}$, which, according to equation (17), are separated from one another by a time interval Δt_B.

$$\Delta t_B = t_{B(j+1)} - t_{Bj} \qquad \text{for values of } j = 1,2,3,\ldots \quad (17)$$

For this purpose, the time-discrete characteristic of the complex, summated impulse response $h_{SFNj}(t)$ and $h_{SFN(j+1)}(t)$ is determined in procedural stage S20 respectively at observation times t_j and $t_{(j+1)}$.

Similarly, in procedural stage S30, the time-discrete characteristics of the complex impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$ of the respective transmitter S_i at the times t_j and $t_{(j+1)}$ are masked out from the time-discrete characteristics of the complex, summated impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$.

Finally, in procedural stage S40, the phase characteristics $\arg(h_{SFNji}(t))$ and $\arg(h_{SFN(j+1)i}(t))$ of the transmitter S_i at the times t_j and $t_{(j+1)}$ are determined from the time-discrete characteristics of the complex impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$.

The subtraction of the phase characteristic $\arg(h_{SFNji}(t))$ from the phase characteristic $\arg(h_{SFN(j+1)i}(t))$ in procedural stage S50 leads to the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacement of the respective transmitter S_i relative to the reference transmitter S_0 between the times $t_{B(j+1)}$ and t_{Bj}, which corresponds to the difference in the phase displacement $\Delta\Theta_i(t_{B(j+1)})$ at the time $t_{B(j+1)}$ and the phase displacement $\Delta\Theta_i(t_{Bj})$ at time t_{Bj} of the transmitter S_i relative to the reference transmitter S_0.

The limitation of the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacement of the respective transmitter S_i relative to the reference transmitter S_0 between the times $t_{B(j+1)}$ and t_{Bj} to the acceptable value range between $-\pi$ and $+\pi$ takes place in procedural stages S60 and S65.

In procedural stage S70, the carrier-frequency displacement $\Delta\omega_{ij}$ of the transmitter S_i is calculated on the basis of the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj}))$ of the phase displacement at the observation times t_j and t_{j+1}, from the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacement of the respective transmitter S_i relative to the reference transmitter S_0 between the times $t_{B(j+1)}$ and t_{Bj}.

The carrier-frequency displacement $\Delta\omega_{ij}$ of the transmitter S_i relative to the reference transmitter S_0 is determined on the basis of the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacement at the observation times t_j and t_{j+1}, at different observation times t_j and t_{j+1}, altogether j_{max}-times, and calculated.

The total of j_{max} calculated carrier-frequency displacements $\Delta\omega_{ij}$ of the transmitter S_i relative to the reference transmitter S_0 is then supplied, in procedural stage S80, for averaging, in order to remove or minimise the influence on the carrier-frequency displacement $\Delta\omega_I$ of the above-named phase disturbances, for example, based on phase noise.

The averaging can also take place in the form of a pipeline structure, wherein the oldest value in each case

is rejected. Recursive averaging is a memory saving variant.

An exemplary characteristic of a carrier-frequency displacement $\Delta\omega_i$ of a transmitter S_i relative to a reference transmitter S_0 is shown in Figure 5B.

A device for monitoring the carrier frequency stability of several transmitters in a single-frequency network is shown in Figure 1.

The single-frequency network shown in Figure 1 consists, for example, of the five transmitters S_1, S_2, S_3, S_4 and S_5. The transmitted signals of the transmitters S_1 to S_5 are received by a receiver device E. The receiver device E is connected to an electronic data-processing unit 1. In a unit 11 for determining the transmission function of the transmission channel, the transmission function $H_{SFN}(f)$ of the transmission channel of the transmitters S_1 to S_5 to the receiver device E is determined on the basis of the transmitted signals received by the receiver device E from the transmitters S_1 to S_5. In this context, use is made of the coefficients of the equaliser integrated in the receiver device E, which correspond, in the case of an equaliser calibrated to the transmission channel, to the coefficients of the transmission function of the transmission channel.

Alternatively, in the case of digital terrestrial TV, the transmission function $H_{SFN}(f)$ of the transmission channel from the transmitters S_1 to S_5 to the receiver device E can be determined from the scattered pilot carriers of a DVB-T signal, thereby bypassing the unit 11.

In a subsequent unit 12 for the implementation of the inverse Fourier transform, the time-discrete characteristics of the complex, summated impulse responses $h_{SFNj}(t)$ and $h_{SFN(j+1)}(t)$ are calculated at the observation times t_{Bj} and $t_{B(j+1)}$ from the transmission function $H_{SFN}(f)$ of the transmission channel.

In a subsequent unit 13 for masking the impulse response for every transmitter out of the summated impulse response, the time-discrete characteristics of the complex impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$ for every transmitter S_i of the single-frequency network at times t_{Bj} and $t_{B(j+1)}$ are masked out from the time-discrete characteristics of the complex summated impulse responses $h_{SFNj}(t)$ and $h_{SFN(j+1)}(t)$.

In a subsequent unit 14 for determining the phase characteristic of the impulse response, the time-discrete phase characteristics $\arg(h_{SFNji}(t))$ and $\arg(h_{SFN(j+1)i}(t))$ of the impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$ at times t_{Bj} and t_{Bj+1} are calculated from the time-discrete characteristics of the complex impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$.

In a subsequent unit 15 for calculating the difference in phase displacement and carrier-frequency displacement of every transmitter relative to the carrier frequency of a reference transmitter from the time-discrete phase characteristics $\arg(h_{SFNji}(t))$ and $\arg(h_{SFN(j+1)i}(t))$ of the impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$ at the times t_j and t_{j+1}, the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacements of a transmitter S_i relative to a reference transmitter S_0 at the observation times t_{Bj} and $t_{B(j+1)}$ is calculated; this corresponds to the

difference in the phase displacement $\Delta\Theta_i(t_{Bj})$ and $\Delta\Theta_i(t_{B(j+1)})$ of the transmitter S_i relative to the reference transmitter S_0 at the times t_{Bj} and $t_{B(j+1)}$, and on this basis, the carrier-frequency displacement $\Delta\omega_{ij}$ for every transmitter S_i relative to a reference transmitter S_0 is derived with reference to a determined phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ of the phase displacements at observation times t_{Bj} and $t_{B(j+1)}$.

In a unit 2 for the tabular and/or graphic presentation of the carrier-frequency displacement $\Delta\omega_i$ of all transmitters S_i, which is connected to the electronic data processing unit 1, the carrier-frequency displacements $\Delta\omega_i$ of every transmitter S_i relative to a reference transmitter S_0 of the single-frequency network are presented either in tabular or graphic form.

Regarding the simultaneous presentation of the amplitude deviation and the carrier-frequency deviation of a transmitter S_i relative to a reference transmitter S_0 at a given observation time t_{Bi} in a graphic display, on the one hand, a three-dimensional presentation can be provided, with time t as a first dimension, frequency deviation $\Delta\omega_i$ of the respective transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 as a second dimension and finally the amplitude deviation ΔA_i of the respective transmitter S_i relative to the amplitude A_i of the reference transmitter S_0 as a third dimension. If the reference transmitter S_0 is set in the three-dimensional graphic display scaled to its amplitude A_0 at time t=0, each transmitter S_i is represented, as shown in Figure 6A, by a point in the graphic display corresponding to the respective amplitude and carrier-

frequency deviation ΔA_i and $\Delta\omega_i$. On the other hand, in the case of a two-dimensional presentation, as shown in Figure 6B, the time t is plotted on the abscissa and the amplitude A_0 of the respective reference transmitter S_0 is plotted on the ordinate, while the carrier frequency deviation $\Delta\omega_i$ of the respective transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 is characterised by a symbol for the point associated with the respective transmitter S_i corresponding to the carrier frequency deviation $\Delta\omega i$. Once again, the amplitude A_0 of the reference transmitter S_0 is entered in the graphic display at time t=0.

The invention is not restricted to the exemplary embodiments presented and described. In particular, all of the features described can be combined freely with one another. The method described is also suitable not only for signals of the DAB or DVB-T standards, but also for all standards, which allow SFN, especially, including signals of the American ATSC standard.

Claims

1. Method for monitoring the stability of the carrier frequency (ω_i) of identical transmitted signals ($s_i(t)$) of several transmitters ($S_1,\ldots,S_i,\ldots,S_n$) of a single-frequency network by evaluating the phase position of a received signal ($e_i(t)$) associated with a transmitted signal ($s_i(t)$) of a transmitter (S_i) with reference to a received signal ($e_0(t)$) of a reference transmitter (S_0), both of which are received by a receiver device (E) positioned within the transmission range of the single-frequency network.

2. Method according to claim 1,
characterised by
a calculation (S70) of a carrier-frequency displacement ($\Delta\omega_i$) of a carrier frequency (ω_i) of a transmitter (S_i) relative to a reference carrier frequency (ω_0) of the reference transmitter (S_0) from a phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) caused by the carrier-frequency displacement ($\Delta\omega_i$) of this transmitter between a phase displacement ($\Delta\Theta_i(t_{B2})$) at least at one second observation time (t_{B2}) and a phase displacement ($\Delta\Theta_i(t_{B1})$) at a first observation time (t_{B1}) of a received signal ($e_i(t)$) of this transmitter (S_i) associated with the transmitted signal ($s_i(t)$) relative to a received signal ($e_0(t)$) of the reference transmitter (S_0) associated with the transmitted signal ($s_0(t)$).

3. Method for monitoring the stability of the carrier frequency according to claim 2,

characterised in that

the calculation (S70) of the carrier-frequency displacement ($\Delta\omega_i$) of the carrier frequency (ω_i) of the transmitter (S_i) relative to the carrier frequency (ω_0) of the reference transmitter (S_0) from the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) is preceded by the procedural stages listed below:

- determination (S10) of a transmission function ($H_{SFN}(f)$) of the transmission channel from the transmitters ($S_1,\ldots,S_i,\ldots,S_n$) to the receiver device (E),

- calculation (S20) of a characteristic of a complex, time-discrete, summated impulse response ($h_{SFN1}(t)$) at the first observation time (t_{B1}) and a characteristic of a complex, time-discrete, summated impulse response ($h_{SFN2}(t)$) at the second observation time (t_{B2}) of the transmission channel respectively from the transmission function ($H_{SFN}(f)$) of the transmission channel,

- masking (S30) of a characteristic of a complex impulse response ($h_{SFN1i}(t)$) at the first observation time (t_{B1}) and of a characteristic of a complex impulse response ($h_{SFN2i}(t)$) at the second observation time (t_{B2}) for every transmitter (S_i) of the single-frequency network respectively from the characteristic of the complex, summated impulse response ($h_{SFN1}(t)$) at the first observation time (t_{B1}) and from the characteristic of the complex,

summated impulse response ($h_{SFN2}(t)$) at the second observation time (t_{B2}),

- determination (S40) of a phase characteristic ($\arg(h_{SFN1i}(t))$) of the complex impulse response ($h_{SFN1i}(t)$) at the first observation time (t_{B1}) and of a phase characteristic ($\arg(h_{SFN2i}(t)$) of the complex impulse response ($h_{SFN2}(t)$) at the second observation time (t_{B2}) for every transmitter (S_i) of the single-frequency network,

- calculation (S50) of the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) between a phase displacement ($\Delta\Theta_i(t_{B2})$) at the second observation time (t_{B2}) and a phase displacement ($\Delta\Theta_i(t_{B1})$) at the first observation time (t_{B1}) by subtraction of a phase characteristic ($\arg(h_{SFN1i}(t))$) of the complex impulse response ($\arg(h_{SFN1i}(t)$) at the first observation time (t_{B1}) from a phase characteristic ($\arg(h_{SFN2i}(t))$) of the complex impulse response ($h_{SFN1i}(t)$) at the second observation time (t_{B2}) of the respective transmitter (S_i).

4. Method for monitoring the stability of the carrier frequency according to claim 3,
characterised by

- increasing (S60) the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) by the factor $2*\pi$ in the case of a decrease in the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) to the value $-\pi$ or below and

- reducing (S65) the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) by the factor $-2*\pi$ in the case of an increase in the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) above the value π.

5. Method for monitoring the stability of the carrier frequency according to claim 3 or 4,
characterised in that
in the case of digital terrestrial TV, the transmission function of the transmission channel from the transmitters ($S_1,\dots,S_i,\dots,S_n$) to the receiver device (E) is determined from the DVB-T symbols of scattered pilot carriers of received signals ($e_i(t)$) of the transmitters ($S_1,\dots,S_i,\dots,S_n$) modulated according to the orthogonal-frequency-division-multiplexing (OFDM) method.

6. Method for monitoring the stability of the carrier frequency according to claim 3,
characterised in that
the calculation (S20) of a characteristic of a complex, time-discrete, summated impulse response $h_{SFN1/2}(t)$ at the discrete first observation time t_{B1} of the transmission channel is derived from the transmission function $H_{SFN}(f)$ of the transmission channel using the Fourier transform according to the formula:

$$h_{SFN1/2}(t) = \sum_{k=0}^{N_F-1} H_{SFN}(k) * e^{j2\pi kt/N_F}$$

wherein

$H_{SFN}(f)$ denotes the transmission function or respectively the frequency response of the transmission channel,

N_F denotes the number of sampling values for the discrete Fourier transform,

k denotes the discrete frequency values,

t denotes the sampling times of the time-discrete, summated impulse response of the transmission channel and

1/2 denotes the index for the observation time t_{B1} or respectively t_{B2}.

7. Method for monitoring the stability of the carrier frequency according to claim 6,
characterised in that
the calculation (S50) of the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) for each transmitter S_i of the single-frequency network is derived according to the formula:

$$\Delta\Delta\Theta_i(t_{B2}-t_{B1}) = \arg(h_{SFN2i}(t)) - \arg(h_{SFN1i}(t))$$

wherein

i denotes the index for the transmitter S_i

$\arg(h_{SFN2i}(t))$ denotes the phase characteristic of the complex impulse response $h_{SFN2i}(t)$ at the observation time t_{B2} of the transmitter S_i and

$\arg(h_{SFN1i}(t))$ denotes the phase characteristic of the complex impulse response $h_{SFN1i}(t)$

at the observation time t_{B1} of the transmitter S_i.

8. Method for monitoring the stability of the carrier frequency according to claim 7,
characterised in that
the calculation (S70) of the carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter of the single-frequency network is derived according to the formula:

$$\Delta\omega_I = \Delta\Delta\Theta_i(t_{B2}-t_{B1})/(t_{B2}-t_{B1})$$

wherein

i	denotes the index for the transmitter S_i,
$\Delta\Delta\Theta_i(t_{B2}-t_{B1})$	denotes the phase position difference $\Delta\Delta\Theta_i(t_{B2}-t_{B1})$ for the transmitter S_i of the single-frequency network and
t_{B1}, t_{B2}	denote the observation times.

9. Method for monitoring the stability of the carrier frequency according to claim 8,
characterised in that
to allow an unambiguous identification of the permanent carrier-frequency displacement $\Delta\omega_i$ of the transmitter S_i in the single-frequency network relative to the carrier frequency ω_0 of the reference transmitter S_0 at several observation times t_{Bj}, the following procedural stages are implemented repeatedly:

- calculation (S20) of the characteristic of the complex, time-discrete, summated impulse response $h_{SFNj}(t)$ and $(h_{SFN(j+1)}(t)$ at the observation times t_{Bj} and $t_{B(j+1)}$,

- masking (S30) of the characteristic of the complex impulse response $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t)$ at the observation times t_{Bj} and $t_{B(j+1)}$ for every transmitter S_i of the single-frequency network,

- determination (S40) of the phase characteristics $\arg(h_{SFNji}(t)$ and $\arg(h_{SFN(j+1)i}(t))$ of the complex impulse responses $h_{SFNji}(t)$ and $h_{SFN(j+1)i}(t))$ at the observation times t_{Bj} and $t_{B(j+1)}$,

- calculation (S50) of the phase-displacement difference $(\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj}))$ between the phase displacement $\Delta\Theta_i(t_{B(j+1)})$ at the observation time $t_{B(j+1)}$ and the phase displacement $\Delta\Theta_i(t_{Bj})$ at the observation time t_{Bj} for every transmitter S_i of the single-frequency network,

- increasing (S60) the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ by the factor $2*\pi$ in the case of a decrease in the phase-displacement difference $(\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj}))$ to the value $-\pi$ or below,

- reducing (S65) the phase-displacement difference $(\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj}))$ by the factor $-2*\pi$ in the case of an increase in the phase-displacement difference $\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$ above the value π and

- calculation (S70) of the carrier-frequency displacement $\Delta\omega_{ij}$ of the transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter of the single-frequency network at several observation times t_{Bj};

and that following this, an averaging (S80) of all carrier-frequency displacements $\Delta\omega_{ij}$ of every transmitter S_i relative to the carrier frequency ω_0 of the reference transmitter S_0 of the single-frequency network calculated respectively in procedural stage (S70), is implemented at the observation times t_{Bj}.

10. Method for monitoring the stability of the carrier frequency according to claim 9,
characterised in that
the averaging (S80) of all carrier-frequency displacements $\Delta\omega_{ij}$ of every transmitter S_i relative to the carrier frequency ω_0 of a reference transmitter S_0 of the single-frequency network calculated in procedural stage (S70), is implemented using a recursive method.

11. Device for monitoring the stability of the carrier frequency (ω_i) of identical transmitted signals $s_i(t)$ of several transmitters ($S_1,\ldots,S_i,\ldots,S_n$) of a single-frequency network comprising:

- a receiver device (E),

- a unit (11) for determining a transmission function $H_{SFN}(f)$ of a transmission channel of

several transmitters ($S_1, \ldots, S_i, \ldots, S_n$) of the single-frequency network to the receiver device (E) disposed within the transmission range of the single-frequency network,

- a unit (12) for implementing an inverse Fourier transform,

- a unit (13) for masking a impulse response ($h_{SFNi}(t)$) for every transmitter (S_i) from the summated impulse response ($h_{SFN}(t)$),

- a unit (14) for determining the phase characteristic ($\arg(h_{SFNi}(t))$) of the impulse response ($h_{SFNi}(t)$) for every transmitter (S_i),

- a unit (15) for calculating the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$) of the phase displacement ($\Delta\Theta_i$) of a transmitter (S_i) relative to a reference transmitter (S_0) at least at two different times (($t_{B1,}-t_{Bj+1}$)) and the carrier-frequency displacement ($\Delta\omega_i$) of every transmitter (S_i) relative to the carrier frequency (ω_0) of the reference transmitter (S_0) and

- a unit (2) for presenting the calculated carrier-frequency displacement ($\Delta\omega_i$) of every transmitter (S_i) relative to the carrier frequency (ω_0) of the reference transmitter (S_0) of the single-frequency network.

12. Device for monitoring the stability of the carrier wave (ω_i) of identical transmitted signals $s_i(t)$ of

several transmitters ($S_1, \ldots, S_i, \ldots, S_n$) of a single-frequency network comprising:

- a receiver device (E),

- a unit (16) for determining a transmission function ($H_{SFN}(f)$) from pilot carriers of the received signal ($e_i(t)$),

- a unit (13) for masking a impulse response ($h_{SFNi}(t)$) for every transmitter (S_i) from the summated impulse response ($h_{SFN}(t)$),

- a unit (14) for determining the phase characteristic ($\arg(h_{SFNi}(t)$) of the impulse response ($h_{SFNi}(t)$) for every transmitter (S_i),

- a unit (15) for calculating the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B(j+1)}-t_{Bj})$) of the phase displacement $\Delta\Theta_i$ of a transmitter (S_i) relative to a reference transmitter (S_0) at least at two different times ($t_{Bj}-t_{B(j+1)}$) and the carrier-frequency displacement ($\Delta\omega_i$) of every transmitter relative to the carrier frequency (ω_0) of the reference transmitter (S_0) and

- a unit (2) for presenting the calculated carrier-frequency displacement ($\Delta\omega_i$) of every transmitter (S_i) relative to the carrier frequency (ω_0) of the reference transmitter (S_0) of the single-frequency network.

13. Device for monitoring the stability of the carrier frequency according to claim 11 or 12,
characterised in that
the unit (2) for presenting the calculated carrier-frequency displacement ($\Delta\omega_i$) of every transmitter (S_i) relative to the carrier frequency (ω_0) of the reference transmitter (S_0) comprises a tabular and/or graphic display device.

Abstract

The method for monitoring the stability of the carrier frequency (ω_i) of identical transmitted signals ($s_i(t)$) of several transmitters S_i of a single-frequency network is based upon a calculation of a carrier-frequency displacement $\Delta\omega_i$ of a carrier frequency ω_i of a transmitter S_i relative to a carrier frequency ω_0 of a reference transmitter S_0. For this purpose, the phase-displacement difference ($\Delta\Delta\Theta_i(t_{B2}-t_{B1})$) caused by the carrier-frequency displacement $\Delta\omega_i$ between a phase displacement $\Delta\Theta_i(t_{B1})$ at a first observation time t_{B1} and a phase displacement $\Delta\Theta_i(t_{B2})$ at a second observation time t_{B2} of a received signal ($e_i(t)$) of the transmitter S_i associated with the respective transmitted signal ($s_i(t)$) is determined relative to a received signal $e_0(t)$ of the reference transmitter S_0 associated with the reference transmitted signal $s_0(t)$.

(Figure 1)